Performance of Equipment for In-Field Shelling of Peanut for Biodiesel Production

C. L. Butts, R. B. Sorensen, R. C. Nuti, M. C. Lamb, W. H. Faircloth

Abstract. *Drying, cleaning, and shelling peanuts represents approximately one-third of the costs of growing, harvesting, and processing peanuts for oil extraction. A conventional two-row peanut combine normally used to thresh windrowed peanuts was modified to shell the peanuts as they were harvested. Peanuts were dug, windrowed, and allowed to partially dry in the windrow. They were then harvested using either the modified peanut combine or a conventional grain combine. As a control treatment, peanuts were harvested using the modified peanut combine with the shelling grates removed from the sheller. The modified peanut combine successfully captured 91% of the peanut kernels threshed by the control and shelled 99% of the kernels harvested. The grain combine captured only 62% of the peanut kernels compared to the control. The grain combine shelled 93% of the peanuts harvested. Peanuts harvested with the grain combine had 30% foreign material, compared to 11% foreign material harvested with the modified peanut combine or the control. Allowing the peanuts to dry in the windrow and shelling with the modified peanut combine reduced the estimated postharvest oil production costs by as much as 36%, from $611 to $391 per 1000 L of oil.*

Keywords. *Biodiesel, Harvester, Peanut, Peanut oil, Sheller.*

Recent fluctuations in the price of petroleum fuels and the economic environment have sparked renewed interest in alternative liquid fuels, such as ethanol and biodiesel. The success and sustainability of a biodiesel production facility, especially a small-scale facility, depend on the cost of the feedstock used (Shumaker et al., 2008). The oil content of peanut seed ranges between 44% and 56% and averages approximately 50% (Ahmed and Young, 1982). The average U.S. in-shell peanut yield between 2000 and 2008 was 3280 kg/ha. With an average 76% kernel mass fraction, peanut has a potential to yield 1246 kg/ha of oil for small-scale biodiesel production. According to Shumaker et al. (2007), the variable costs of producing peanut oil for fuel is $621 per 1000 L using conventional production methods (table 1). Peanut production costs can be significantly reduced and consistently achieve yields between 2200 and 3100 kg/ha by using peanut cultivars with tolerance to multiple diseases to eliminate fungicide applications for disease control, reduced tillage, and other low-input production practices (Faircloth et al., 2007, 2008). Using budget estimates of Shumaker et al. (2007), production costs can be reduced to approximately $323 per 1000 L of oil (table 1).

Under ideal weather conditions, peanuts are usually dug, inverted, and windrowed and then allowed to partially cure (dry) in the windrow to reduce the kernel moisture content to between 20% and 15% wet basis (w.b.). A peanut combine separates peanut pods from the vine (typically called threshing, combining, or harvesting), and the in-shell peanuts are loaded into drying wagons and transported to a central facility. The peanuts are then mechanically dried to a moisture content of 8% to 10%. Depending on the region of the country and weather conditions at harvest, over 90% of all peanuts harvested are mechanically cured. After curing, the in-shell, a.k.a. farmer stock, peanuts are off-loaded into large bulk storage facilities. Approximately 1/3 of the peanuts are cleaned to remove excess foreign material during the transfer from drying wagons into bulk storage. Following bulk storage, the farmer stock peanuts are unloaded and transported to the shelling plant for cleaning and separating the kernel from the shell (hull). According to budgets presented by Shumaker et al. (2007), the variable cost of postharvest processing from harvest through shelling is $611 per 1000 L of oil (table 1). In a conventional peanut production system, postharvest processing represents approximately 49% of the cost of getting peanut kernels ready to crush for oil. In a reduced-input production system, the postharvest processing represents 65% of the processing cost.

The single largest cost associated with the postharvest processing is transportation and storage of the farmer stock peanuts (46%). Cleaning, drying, and shelling constitute 38% of the postharvest processing costs (table 1). In the case of a grower producing peanuts strictly for oil, drying costs could be eliminated or greatly reduced by allowing the peanuts to completely dry in the windrow. Transportation and storage costs could be reduced by storing the farmer stock peanuts on farm in unused drying wagons. Many growers implement this storage practice when producing their own pea-

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Table 1. Comparison of estimated variable production and processing costs for peanuts grown for biodiesel production using conventional and minimal production practices.

Variable[a]	No. of Units	Unit Cost ($)	Cost per ha ($)	Cost per 1000 L of Oil[b] ($) Conventional	Cost per 1000 L of Oil[b] ($) Minimum input
Preharvest					
Seed	130 kg/ha	1.14/kg	148.20	119.03	119.03
Inoculant	5.6 kg/ha	3.08/kg	17.25	13.85	
Lime/gypsum	1.1 t/ha	69.44/t	76.38	8.03	8.03
Fertilizer[c]	68.3 kg/ha	0.29/kg	19.81	15.91	
Weed control	1 appl./ha	102.41/appl.	102.41	82.26	50.00[d]
Insect control	1 appl./ha	62.93/appl.	62.93	50.55	
Disease control	7 appl./ha	24.13/appl.	168.91	135.67	
Labor	6.25 h/ha	10.00/h	62.50	50.20	50.20
Machinery fuel	88.7 L/ha	0.59/L	52.33	42.03	42.03
Machinery repair and maintenance	1	34.09/ha	34.09	27.38	27.38
Crop insurance	1	37.05/ha	37.05	29.76	
Interest on operating		8%		45.97	26.31
Total preharvest variable costs:			807.59	620.64	322.98
Postharvest					
Machinery fuel	76.6 L/ha	$ 0.59/L	45.20	36.31	36.31
Machinery repair and maintenance	1	$ 40.30 /ha	40.30	32.37	32.37
Cleaning	0.47 t/ha	$ 11.76/t	17.29	13.89	13.89
Drying	2.92 t/ha	$ 29.12/t	85.03	68.30	68.30
Transportation and storage	3.14 t/ha	$112.78/t	354.13	284.44	284.44
Shelling	3.14 t/ha	$ 51.52/t	162.71	130.69	130.69
Interest on operating		8%		45.28	45.28
Total postharvest variable costs:				611.28	611.28
Total variable production costs:				1213.92	934.26

[a] Budget information from Shumaker et al. (2007).
[b] Assume 1245 L/ha oil yield (3.14 t/ha in-shell peanuts, 76% kernel content, 48% oil content in kernels, oil density 0.916 g/cm3).
[c] Fertilizer consists of 33% phosphate (P_2O_5), 66% potash (K_2O), and 1% boron.
[d] Faircloth et al. (2008).

nut seed. However, custom shelling at local seed shelling facilities costs approximately $110/t of farmer stock or the equivalent of $276 per 1000 L of oil. Using or modifying existing combining equipment to shell peanuts in the field could further reduce the cost of producing peanuts to be processed for oil or fuel.

The sheller consists of a concave grate that extends 180° to 270° around a shelling cylinder with an 8 to 28 cm wide opening at the top of the grate through which the peanuts enter the sheller. The shelling cylinder rotates at speeds between 160 and 300 rpm and shells the peanuts as they fall into the space between the concave grate and the shelling cylinder. The peanut fractions, whole seed, split and broken seed, hulls, and unshelled pods fall through the grate into an airstream to aspirate the hulls from the flow (Davidson et al., 1982). The remaining material is separated into shelled and unshelled fractions using sizing screens and gravity tables. According to Davidson et al. (1976), the shelling efficiency, or percentage of peanuts shelled in a single pass through the sheller, is determined by grate size, distance between the cylinder and the grate, cylinder speed, and the width of the feed opening.

Examination of a typical grain combine revealed that the concave and cylinder arrangement is similar to that of a commercial peanut sheller. The cylinder is a closed-type cylinder with rasp bars compared to the open-type cylinder in a typical peanut sheller. The straw walkers and sieves in a grain combine are similar to the straw walkers and screens used in peanut combines to separate the threshed peanut pods from the hay. A windrow header for the grain combine would most likely feed the peanut windrow into the throat, but the question of whether a grain combine would successfully thresh and shell peanuts remained.

The typical peanut combine is designed to lift the windrow and separate peanut pods from the vines (called threshing, combining, or harvesting) and then transport the unshelled peanuts into a hopper. Peanuts are typically harvested and delivered to a peanut buying facility with less than 3% loose shelled kernels and less than 5% foreign material (FM). Loose shelled kernels, or LSK, are peanuts that are shelled due to mechanical damage during combining and subsequent handling and storage before reaching the shelling plant. Many times, commercial shelling facilities are equipped with additional cleaning equipment to remove the FM and segregate the LSK from the peanut pods to improve shelling efficiency. However, the LSK peanuts are primarily used as inedible product. Peanuts that are typically crushed for oil do not have to be as clean and may have as much as 10% FM (Lonnie Sellars, Sessions Company, personal communication, 6 Feb. 2007).

A study was conducted to explore the possibility of shelling peanuts during harvest to reduce the overall cost of growing and processing peanuts for on-farm biodiesel production. Specific objectives of the study were to:

- Harvest and shell peanuts using conventional grain harvesting equipment.
- Modify an existing peanut combine to shell peanuts during harvest.
- Evaluate and compare harvesting and shelling performance of grain and modified peanut combines.

Materials and Methods

2007 Grain Combine Test

Peanuts were dug and inverted into windrows following conventional digging techniques using a two-row digger/inverter in mid-October 2007. Peanuts remained in the windrow for approximately two weeks until kernel moisture content was less than 10% so that no mechanical drying would be required for safe storage. A grain combine (model 4420, John Deere, Moline, Ill.) was used to harvest a 15 m section of windrow. The threshing cylinder was a rasp bar cylinder with cylinder filler plates installed. A windrow header for the combine was not available; therefore, the dried peanut vines were manually fed onto the receiving auger of the corn header using a pitchfork. The harvested material was captured using a bagging attachment in the grain holding tank. The test was conducted using three replicates of each combination of three threshing cylinder speeds (475, 740, and 1030 rpm) and three cylinder-concave spacing settings (0, 2, and 4). The cylinder speeds chosen were higher than the 300 rpm normally observed in a peanut sheller but were within the normal operating range of the combine without modification. Grasses and clover are typically harvested with a recommended cylinder-concave gap setting of 0 (7 mm); mustard, oats, and sorghum with a setting of 2 (15 mm); and soybean and rape are harvested using a cylinder-concave setting of 4 (20 mm). Shelled peanuts are sized similarly to soybean. Fan speed was set at 964 rpm throughout all tests. Material exiting the straw walkers was qualitatively examined periodically during the tests to check for unthreshed peanut pods, unshelled peanut pods, and shelled peanut kernels. No samples were collected or analyzed from the material exiting the machine. Peanut samples were divided twice using a riffle divider so that one-quarter of the original sample was analyzed. Each sample was processed to separate foreign material, shelled peanuts, and unshelled peanuts. Each component was weighed, and the mass fraction of each was calculated.

A second, unreplicated test was conducted in a separate field during which the cylinder speed was a constant 1030 rpm and the cylinder-concave spacing was set at 7 mm (setting 0). Six 15 m windrows were harvested while varying the fan speed from approximately 900 to 1000 rpm and varying the settings for the sieves in the rear of the machine to reduce foreign material in the shelled peanut material.

Peanut Combine/Sheller Design

A used two-row peanut combine (HU2000, Gregory Mfg. Co., Lewiston, N.C.) was obtained and modified to shell peanuts during harvest. The holding bin normally used to hold the threshed peanut material was removed and replaced with a salvaged cast iron peanut sheller and surge hopper to feed the sheller (fig. 1). A sliding gate was installed to control the flow of threshed peanuts from the surge hopper into the sheller. The sheller has three ripple-edged shelling bars and four sections of grates, as described by Davidson et al. (1976). As peanuts fall into the shelling chamber, the shelling bars aggressively rub the peanut pods against the grates until the kernels and hulls are separated. Both the kernels and hulls fall down through the grate into an upward flowing airstream that aspirates the hulls from the kernels (fig. 2). The kernels then fall into an auger where they are transferred to a bag via a bagging attachment.

The peanut combine is powered by the tractor 540 rpm power takeoff (PTO). A right-angle gearbox transmits the power from the PTO shaft to a drive shaft extending to the right-hand side of the combine. A series of sheaves and belts transmit power to the various threshing mechanisms. A chain and sprocket transmits power from the main drive shaft to the pick-up head. Power was transmitted to the sheller by removing the main drive sheave (fig. 3) and installing a sheller drive sprocket on the shaft. The main drive sheave was then reinstalled in its original position. The sheller drive sprocket and sheller sprocket are the same diameter and have the same number of teeth, resulting in a 1:1 speed ratio. At 540 PTO rpm, the sheller turns at approximately 320 rpm. The shaft for the sheller extends completely through the sheller, with a smaller sprocket to drive the shelled stock transfer auger.

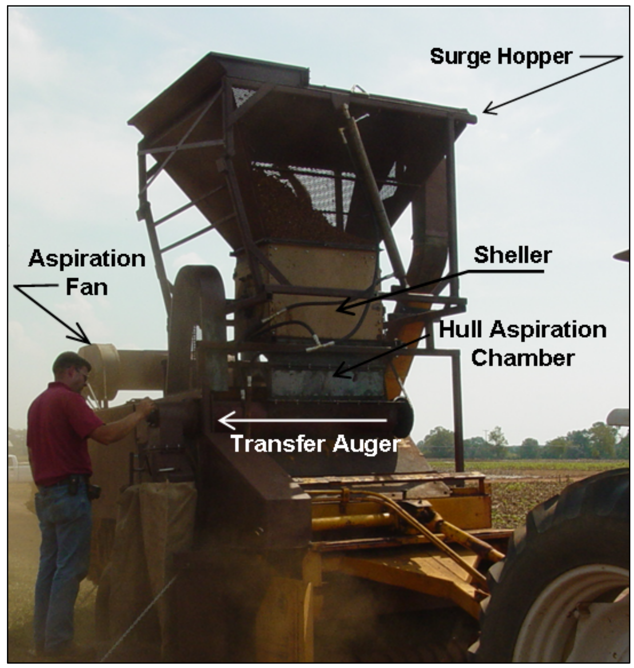

Figure 1. Two-row peanut combine modified to shell peanuts while harvesting.

Figure 2. Transition from shelling chamber through hull aspiration to shelled peanut transfer auger.

Figure 3. Modification of peanut combine drive system to power the on-board peanut sheller.

The surge hopper feeding the sheller was sized to hold approximately 500 kg of in-shell peanuts. Slide gates at the bottom of the hopper may be used to regulate the flow of material into the sheller. However, the slide gates are intended to be fully opened under normal use and closed for use in the event that the sheller must be stopped and cleaned out. The surge hopper is equipped with hydraulic cylinders to empty the hopper, if necessary, and allow access to the sheller for maintenance.

The hull aspiration unit has an air duct that spans the full width of the sheller discharge chute and intersects with the sheller discharge such that airflow into the aspiration system is upwards through the peanuts (fig. 2). An air inlet measuring 5 cm tall by 1 m long was incorporated into the transfer auger housing (fig. 3). The hull aspiration duct then connects to the intake of two straight-vane centrifugal blowers connected in parallel (fig. 1). A single shaft extends from the left side of the machine through both blowers. Each fan exhausts air and aspirated material from the sheller through the rear of the peanut combine, where threshed peanut vines normally exit. A damper was installed in the aspiration duct to control the airflow through the aspiration system. If aspiration airflow rate is too low, then hulls and other light trash will remain with the shelled peanuts. If the aspiration airflow rate is too high, then kernels will be aspirated with the hulls and expelled from the machine.

Previous shelling research (Davidson and McIntosh, 1973; Davidson and Hudgins, 1979) resulted in a small-scale Model 4 peanut sheller that yielded whole and split kernel outturns and shelling efficiency similar to that of commercial cast iron shellers (Davidson et al., 1976). A Model 4 sheller was used to determine the shelling grate size to use in the combine/sheller. Three replicates of four different grate sizes (10.3, 9.5, 7.1, and 6.3 mm) were used to shell twelve 2 kg samples. Pod size distribution of each sample was determined prior to shelling. The sample was poured into a hopper above the shelling chamber, and the sheller was allowed to attain full speed prior to opening the hopper gate to allow peanuts into the shelling chamber. The shelling time for each sample and the weight of peanuts remaining in the sheller were recorded. The sample was then analyzed, recording the weight of shelled and unshelled peanuts.

2008 Field Tests

Peanuts were grown in 50 m long research plots and then dug, inverted, and windrowed at optimum maturity according to conventional practice. After partially curing in the windrow, the peanuts were separated into 15 m sections. Using optimum settings found during the 2007 harvest, one 15 m section was manually fed into the grain combine, and the harvested peanuts were captured as described previously. This was repeated two more times to obtain three replicated samples. The peanut combine/sheller was used to harvest three 15 m sections of windrow, collecting the peanuts harvested from each section separately using the bagging attachment on the combine. The peanut combine/sheller test was repeated using a second setting on the hull aspiration damper. Finally, as a control, three 15 m windrows were harvested using the combine/sheller with the shelling grates removed and the hull aspiration system closed. This would closely represent a conventional peanut combine harvest.

Each sample was weighed to calculate the harvested kernel yield from each plot. After weighing, the sample was riffle divided until a subsample of 1000 to 2000 g was obtained for further analysis. Each subsample was separated into foreign material, shelled peanuts, and unshelled peanuts, and each component was weighed. The unshelled peanuts were shelled and weights of the kernels and hulls recorded. The mass fractions of each component of the original sample (foreign material, shelled peanuts, and unshelled peanuts) were calculated for each sample. The total percent of peanut kernels shelled was calculated by dividing the weight of the shelled peanut kernels by the total peanut kernel weight. Data were analyzed using paired t-tests to determine the effect of combine type and the number of days in the windrow. Samples collected using the peanut combine/sheller were analyzed to determine the effect of aspiration damper setting on the harvested kernels per unit ground area.

Results

2007 Grain Combine Test

Between 45% and 80% of the peanuts harvested using the grain combine during 2007 were shelled (fig. 4). Cylinder speed accounted for most of the variation in percent kernels shelled. Percent kernels shelled increased with increasing cylinder speed, with the maximum shelling percentage occurring at the maximum cylinder speed of 1030 rpm. This relationship held true regardless of the concave opening used. There were no differences in the percent peanuts shelled between the open (20 mm) and partially open (15 mm) cylinder-concave spacings. However, when the cylinder-concave spacing was closed (7 mm), the percent peanuts shelled in-

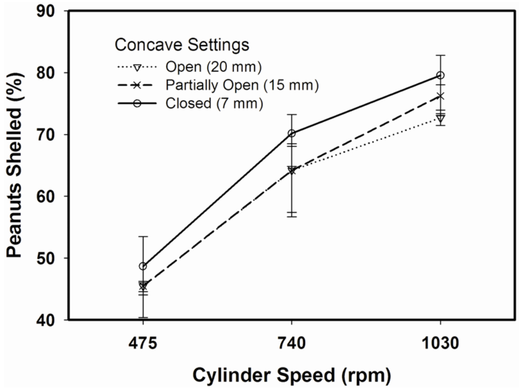

Figure 4. Effect of cylinder speed and concave setting on percent of peanuts shelled using a conventional grain combine (John Deere model 4420).

creased approximately 5 percentage points compared to the partially open and open cylinder-concave spacing.

Foreign material in the harvested peanuts decreased from approximately 13% to 8% as the fan speed on the combine increased from 900 to 960 rpm (fig. 5). However, foreign material remained at approximately 8% when the fan speed was increased from 960 to 1060 rpm.

Very few peanut kernels were observed in the material expelled from the straw walkers of the combine. Observations noted that any pods that remained attached to the vines exiting the rear of the machine were empty or had very small undeveloped kernels in them. Visual inspection revealed that the shelled peanut kernels were mostly broken pieces with very few whole or split halves. Based on these results, further testing and comparison was conducted in 2008 using a closed (7 mm) cylinder-concave spacing, a cylinder speed of 1000 rpm, and a fan speed of at least 950 rpm.

Shelling Grate Selection

As expected, shelling grate size had a significant effect on the percentage of peanut kernels shelled in a sample. The shelled fraction of peanuts decreased exponentially as shelling grate size in the Model 4 sheller increased (fig. 6). Less than 70% of the peanut kernels were shelled when the grate size was 10.3 mm. However, the shelled fraction was greater than 90% when the shelling grate size was 9.5 mm or smaller, and approached 100% as the grate size decreased to 7.1 mm. Regression analysis of the data (AISN, 2000) showed that the

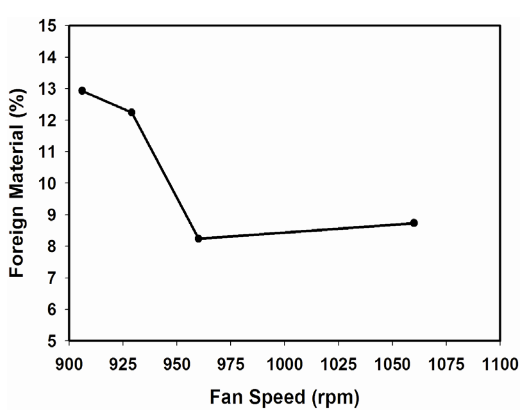

Figure 5. Effect of fan speed on foreign material in peanuts harvested using a conventional grain combine (John Deere model 4420).

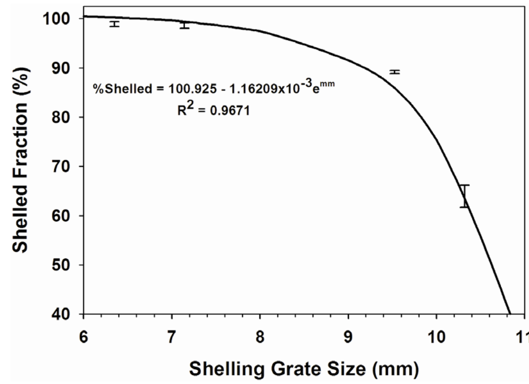

Figure 6. Effect of shelling grate size on percent kernels shelled when using a Model 4 peanut sheller.

shelled fraction could be estimated ($R^2 = 0.9671$) from the shelling grate size (mm) using an exponential equation:

$$\%\,\text{Shelled} \;=\; 100.925 - 1.16209\times 10^{-3}\, e^{mm} \qquad (1)$$

If 90% is the minimum shelled percent desired, then solving the above equation for grate size results in a maximum grate size of 8.8 mm. The sheller installed on the peanut combine requires four sections of shelling grates to cover the 270° shelling area. The bottom two sections of shelling grate were 8.8 mm grates, and the upper two grates were 9.5 mm grates. This was done in an effort to ensure adequate shelling capacity while harvesting.

2008 Field Tests

Two different peanut cultivars were dug and inverted on two separate dates for the in-field tests: DP-1(Gorbet and Tillman, 2008) were dug on 23 September 2008, and Georganic (Holbrook and Culbreath, 2008) were dug on 29 September 2008. The DP-1 peanuts were harvested after 7, 9, and 15 days in the windrow (DIW). The Georganic peanuts were harvested after 8, 16, 18, and 23 days in the windrow. The grain combine was used to harvest the DP-1 peanuts after 7 and 9 DIW and the Georganic peanuts after 8 DIW. After these three harvests, the water pump on the grain combine's engine failed, rendering it inoperable for the remainder of the harvest season. The composition of the harvested material, i.e., foreign material (FM) and shelled and unshelled peanuts, was only affected by the type of combine. Peanut cultivar and the number of days in the windrow did not affect the composition (table 2). Peanuts harvested using the grain combine had 30.6% foreign material. Most of the foreign material in these samples was soil that had adhered to the peanut pod after digging and was not separated from the peanut material in the combine. However, the peanuts harvested using the peanut combine without the shelling grates installed (control) had only 10.5% foreign material, most of which was pieces of dried peanut vine and peanut hulls. The peanut combine with the shelling grates installed had 12.1% foreign material and was not significantly different than the control.

The percent foreign material in the control and modified peanut combine was higher than the normal 3% to 5% in a typical load of peanuts. However, according to anecdotal data and user feedback, this model peanut combine historically has higher foreign material, which would be exacerbated by the very dry vine conditions at harvest.

Table 2. Statistical summary of the sample composition and performance of three peanut harvesting methods.

Treatment		Sample Composition (P > F)			Harvester Performance (P > F)	
		Foreign material	Shelled peanuts	Unshelled peanuts	Kernels shelled	Kernels harvested
Harvester		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cultivar		0.0691	0.1286	0.3018	0.6183	0.9734
Days in windrow		0.5227	0.9205	0.7229	0.1645	0.0453
		Treatment Means (%)[a]				
Harvester	Control[b]	10.5 a	6.3 a	82.9 a	9.4 a	100.0 a
	Modified combine	12.1 a	86.7 b	0.6 b	99.6 b	90.9 b
	Grain combine	30.6 b	61.1 c	6.3 c	93.4 c	62.4 c
Cultivar	DP-1	16.8 a	59.3 a	23.0 a	74.6 a	87.1 a
	Georganic	14.2 a	61.9 a	23.2 a	75.7 a	86.0 a
Days in windrow	7	16.8 a	59.4 a	22.4 a	75.9 a	81.9 a
	8	14.2 a	61.9 a	23.2 a	75.7 a	86.0 ab
	9	16.8 a	59.2 a	23.5 a	73.2 b	92.7 b

[a] Means within the same column followed by the same letter are not significantly different at $\alpha = 0.05$.
[b] The control was the modified peanut combine with the shelling grates removed from the sheller to simulate a conventional peanut combine.

The shelled and unshelled peanut fractions of the harvested material were highly dependent on the harvester type. The material harvested using the control consisted of only 6.3% shelled peanuts. This is slightly higher than the 3% to 4% shelled kernels normally found in a load of peanuts. The material harvested using the grain combine was 61.1% shelled peanuts and 6.3% unshelled peanuts. This was significantly different from the modified peanut combine sample, which was 86.7% and 0.6% shelled and unshelled peanuts, respectively. If the peanut material harvested in these tests was used as feedstock for an oil expeller, then the peanuts harvested with the grain combine would require further processing to remove the excessive foreign material. The peanuts shelled in the grain combine were broken into many small pieces, with many smaller than a quarter kernel. There were very few, if any, whole kernels observed in the grain combine material. This would make it difficult to remove the foreign material from the feedstock by size separation because the soil particles and peanut granules were of very similar size and density.

The shelling and harvest efficiency of the three harvest methods were examined (table 2). The shelling efficiency, or percent kernels shelled, was calculated by dividing the weight of shelled peanuts by the total weight of kernels harvested. To calculate the harvest efficiency, it was assumed that the harvestable peanut kernel yield (kg/ha) was uniform across all plots harvested on a single day. The average total kernel weight harvested by the control treatment (modified combine with no grates installed) for each harvest date was calculated. Harvest efficiency was then calculated for each replication by dividing the kernel weight harvested by the control's average total kernel weight and presented as a percentage. Therefore, the average harvest efficiency for the control was 100%. The control shelled an average of 9% of the kernels harvested, compared to 93.4% and 99.6% shelled using the grain combine and the modified peanut combine, respectively. While the grain combine shelled 93% of the harvested peanut kernels, it only captured 62.4% of the harvestable peanut kernels. This may have been influenced by the fact that peanut vines were manually fed into the grain combine with the corn header still in place. Some peanut pods may have been detached from the dried vines when pitched onto the header table and then transported across the header table by a feed auger to the throat of the combine. While this is a plausible explanation for some of the reduction in harvested kernels, it does not account for the majority of the loss. A pickup mechanism on a peanut combine is a windrow pickup header that lifts the peanut vines from the ground into an open feed auger similar to that on the grain combine. The modified peanut combine, however, harvested 90.9% of the harvested peanut kernels. While days in the windrow had only marginal effect on the shelling and harvest efficiency, it was interesting to note that the harvest efficiency tended to increase as the peanuts were allowed to remain in the windrow longer.

Tests were conducted using the modified peanut combine on peanuts allowed to remain up to 23 DIW. When averaged over the entire harvest season (table 3), the modified peanut combine performance was similar to that of the first three harvest sessions. The foreign material comprised 11.8% of the harvested material but was not significantly different from the 10.4% foreign material collected in the control. As in earlier tests, the modified peanut combine harvested 93.4% of the harvestable peanut kernels, and 99.7% of the harvested kernels were shelled.

Table 3. Statistical summary of the performance of a modified peanut combine during the 2008 peanut harvest.

Treatment		Sample Composition (P > F)			Harvester Performance (P > F)	
		Foreign material	Shelled peanuts	Unshelled peanuts	Kernels shelled	Kernels harvested
Cultivar		0.0022	0.0037	0.0689	0.1737	0.0658
Days in windrow		0.2524	0.2247	<0.0001	0.0035	0.0106
Hull fan		0.0095	0.0072	0.5647	0.4591	0.6219
		Treatment Means (%)[a]				
Cultivar	DP-1	14.1 a	85.0 a	0.4 a	99.7 a	95.7 a
	Georganic	10.3 a	88.7 b	0.5 a	99.6 b	89.6 a

[a] Means within the same column followed by the same letter are not significantly different at $\alpha = 0.05$.

Statistical analysis indicated that the cultivar and days in the windrow affected the composition of the harvested material and the harvest efficiency. On average, the DP-1 peanuts had more foreign material than the Georganic peanuts (14.1% and 10.3%, respectively). This was most likely due to the brittleness of the vines at the time of harvest. The decreased foreign material in the Georganic peanuts was accompanied by an increased percentage in shelled peanuts. There were no differences due to cultivar in the unshelled peanut pods, the percent of kernels shelled, or the percent kernels harvested.

The hull fan setting was varied from approximately 25% open (hull setting 1) to approximately 75% open (hull setting 5). As the damper is opened, it allows the fans to draw more air through the aspiration column to remove more material from the stream of shelled peanut material. A proper setting will aspirate the low-density material (soil, hulls, stems, etc.) from the shelled peanut stream and allow the higher-density shelled peanuts to fall into the transfer auger. The foreign material component of the harvested material remained constant for hull settings 1 and 2 but then decreased from 13% to 8% as the hull fan setting was adjusted from 2 to 5 (fig. 7). A corresponding increase in the shelled kernel component of the peanut material was observed, which increased from 85% to 91%. The unshelled component of the shelled material was not affected by the hull fan setting and remained below 1%. Harvest efficiency was also not affected by the hull fan (data not shown). This suggests that the airflow did not reach high enough levels to aspirate significant amounts of peanut kernels from the stream and expel them with the hulls. This further suggests that there is sufficient fan capacity to increase the sheller throughput if needed.

The number of days in the windrow had a significant effect on the harvest efficiency of the modified peanut combine (figs. 8 and 9). During the initial drying phase in the windrow, the vines and the pods both lose moisture. Under good drying conditions, the vines will dry to a point where they are brittle and the pods and vines can be separated efficiently. The weather conditions after digging and inverting the DP-1 cultivar were clear and dry, allowing the kernel moisture content to reach approximately 9% after 7 days in the windrow (fig. 8). Harvest efficiency was approximately 90% at that point. After 2 more days in the windrow, the moisture content decreased to approximately 7% and harvest efficiency increased to approximately 95%. Harvesting the peanuts after 15 days in the windrow only decreased the moisture content to approximately 6.5%, but the harvest efficiency decreased

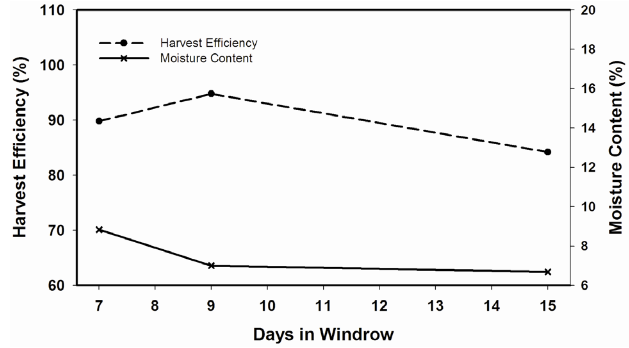

Figure 8. Harvest efficiency and moisture content versus the number of days in windrow when harvesting peanut variety DP-1 with a modified peanut combine.

to approximately 85%. This trend is similar to harvest with conventional peanut combines in which there is an optimum time in the windrow at which harvest losses are minimized and after which harvest losses increase (Young et al., 1982).

Similar trends were observed as the Georganic peanuts were harvested. However, the weather conditions were such that the peanuts had only dried to 13% after 8 days in the windrow. Harvest efficiency at that time was approximately 88% of the control (fig. 9). Rain (11 mm) was received on the 9th day in the windrow, and 6 mm on the 18th day in the windrow. The first rain event rewet the peanuts in the windrow, and after a total of 16 days in the windrow, they had reached 13% again. Rain on windrowed peanut tends to weaken the vines and hulls, enabling the peanuts to be shelled more easily, and allowing the aspiration system to separate any additional foreign material. The modified peanut combine apparently captured 6% more of the harvestable peanut kernels than the control. However, as the peanuts continued to cure in the windrow, the moisture content dropped precipitously from 13% to 8% between 16 and 18 days in the windrow. The moisture content continued to decrease to approximately 6.5% through the last harvest after 23 days in the windrow. The harvest efficiency also dropped to approximately 90% after 23 d.

Since the modified peanut combine harvested and shelled an average of 91% of the peanut kernels compared to a conventional peanut combine, the postharvest processing costs for biodiesel can be reduced. Using the budget costs from table 1 as the basis for conventional harvest, postharvest processing costs per 1000 L of harvestable oil were deter–

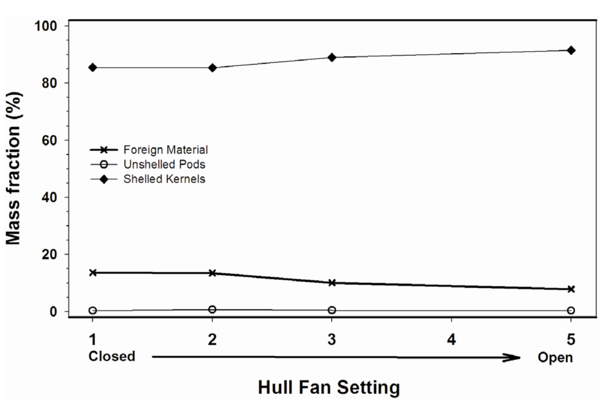

Figure 7. Effect of hull fan setting and harvested peanut constituents.

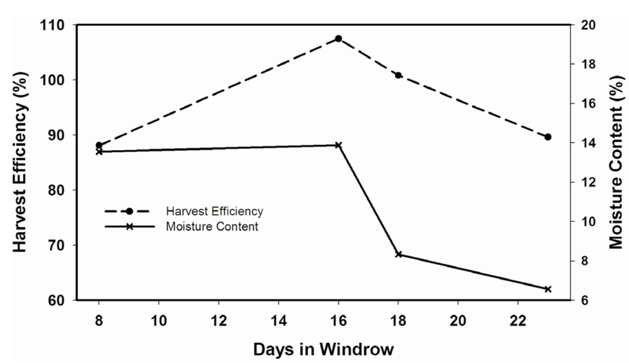

Figure 9. Harvest efficiency and moisture content versus the number of days in windrow when harvesting peanut cultivar Georganic with a modified peanut combine.

Table 4. Comparison of estimated variable postharvest processing costs for peanuts grown for biodiesel production using conventional and in-field drying and shelling.

	Conventional	Modified Peanut Combine		Grain Combine	
Variable Costs	Cost ($/1000 L)	Harvest Efficiency	Cost ($/1000 L)	Harvest Efficiency	Cost ($/1000 L)
Machinery fuel	36.31	90.9%	39.94	62.4%	58.19
Machinery repair and maintenance	32.37		35.61		51.88
Cleaning	13.89		0.00		0.00
Drying	68.30		0.00		0.00
Transportation and storage	284.44		284.44		284.44
Shelling	130.69		0.00		0.00
Interest on operating	45.28		31.08		45.27
Total postharvest variable costs	611.28		391.07		439.78

mined using a grain combine and a modified peanut combine. Since the percent kernels harvested by the alternative combines was less than with the conventional combine, the potential oil yield per ha would be less. If one assumes that the operating and maintenance costs per ha for all three harvesters were the same, then the cost per 1000 L of harvested oil can be estimated by dividing the conventional operating costs by the harvest efficiency of the desired harvester (table 4).

Allowing the peanuts to completely cure in the windrow to a level that does not require mechanical drying removes $68.30 per 1000 L from either of the alternative harvest scenarios. Additional tests indicated that the level of cleaning achieved in the alternative harvest methods was sufficient to maintain the efficiency of the expeller (data not shown), thus eliminating the need for additional cleaning and reducing the costs by another $13.89 per 1000 L. Transportation and storage costs were assumed to be the same as with the conventional method. However, this assumption may not be entirely true, because the weight of material actually transported from the field and stored would be less and the shelled peanuts could be stored in a low-cost structure in 1 t containers until crushed. As presented, the storage and transportation costs show a worst-case scenario for the alternative handling systems.

Allowing the peanuts to dry in the windrow and then harvesting with a modified peanut combine could reduce harvesting costs by approximately 41%, from $611 to $391 per 1000 L of oil. Using a conventional grain combine in the same scenario would potentially reduce the postharvest costs by 28% to $440 per 1000 L. However, repair and maintenance costs would most likely be higher for the grain combine because it is not designed to handle the excessive amounts of soil typically accompanying peanuts during the harvest.

Conclusion

Examination of conventional peanut harvesting, curing, and processing systems for biodiesel production revealed that the majority of the postharvest processing costs occur in curing, cleaning, and shelling the peanut. Alternatives to conventional methods for harvesting, curing, and processing peanut for biodiesel production were investigated to reduce the unit costs. A peanut combine was modified by installing a conventional peanut sheller and associated drive components. The modified peanut combine harvested and retained 91% of the peanut kernels and shelled over 99% of the kernels harvested compared to a conventional peanut combine. A grain combine harvested 62% of the peanuts compared to the conventional peanut combine and shelled 93% of the peanut kernels harvested. Harvesting, curing, and processing costs could be reduced from $611 to $391 per 1000 L of harvestable peanut oil by allowing the peanuts to dry in the field and by harvesting with a peanut combine modified to shell peanuts during harvest.

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References

Ahmed, E. M., and C. T. Young. 1982. Composition, quality, and flavor of peanuts. In *Peanut Science and Technology*, 660-666. Yoakum, Tex.: American Peanut Research and Education Society.

AISN. 2000. *TableCurve 2D for Windows.* Version 5.0. Mapleton, Ore.: AISN Software.

Davidson, J. I., Jr., and R. F. Hudgins. 1979. Development of a peanut sheller for laboratory and industrial applications. *Proc. American Peanut Res. Educ. Soc.* 11(1): 43 (abstract).

Davidson, J. I., Jr., and F. P. McIntosh. 1973. Development of a small laboratory sheller for determining peanut milling quality. *J. American Peanut Res. Educ. Assoc.* 5(1): 95-108.

Davidson, J. I., Jr., R. S. Hutchison, and F. P. McIntosh. 1976. Some performance characteristics of the standard cast-iron peanut sheller. ARS-S-129. Washington, D.C.: USDA-ARS.

Davidson, J. I., Jr., T. B. Whitaker, and J. W. Dickens. 1982. Grading, cleaning, storage, shelling, and marketing of peanuts in the United States. In *Peanut Science and Technology*, 571-623. Yoakum, Tex.: American Peanut Research and Education Society.

Faircloth, W. H., D. L. Rowland, M. C. Lamb, and J. P. Davis. 2007. Evaluation of peanut cultivars for suitability in biodiesel production systems. *American Peanut Res. Ed. Soc. Proc.* 39: 27 (abstract).

Faircloth, W. H., J. A. Ferrell, and C. L. Main. 2008. Weed-control systems for peanut grown as a biofuel feedstock. *Weed Tech.* 22(4): 584-590.

Gorbet, D. W., and B. L. Tillman. 2008. Registration of 'DP-1' peanut. *J. Plant Registrations* 2(3): 200-204.

Holbrook, C. C. and A. K. Culbreath. 2008. Registration of 'Georganic' peanut. *J. Plant Registrations* 2(1): 17.

Shumaker, G., J. C. McKissick, and N. Smith. 2007. Economics of peanuts for biodiesel production. CR-07-04. Athens, Ga.: University of Georgia, Center for Agribusiness and Economic Development. Available at: www.caed.uga.edu/publications. Accessed 11 February 2009.

Shumaker, G. A., A. Luke-Morgan, and J. C. McKissick. 2008. Small-scale biodiesel production: What you need to know before you get started. CR-09-03. Athens, Ga.: University of Georgia, Center for Agribusiness and Economic Development. Available at: www.caed.uga.edu/publications. Accessed 11 February 2009.

Young, J. H., N. K. Person, J. O. Donald, and W. D. Mayfield. 1982. Harvesting, curing, and energy utilization. In *Peanut Science and Technology*, 458-485. Yoakum, Tex.: American Peanut Research and Education Society.